EFFECTS OF COMPETITIVE AND ALLELOPATHIC INTERACTIONS ON FIELD PEA AND SOYBEAN UNDER ORGANIC MANAGEMENT

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ABSTRACT

Experiments were conducted during 2011 and 2012 at Dickinson Research Extension Center (DREC), ND and at Carrington Research Extension Center (CREC) to understand the effects of competitive and allelopathic interactions on field pea and soybean under organic management. Another preliminary controlled environmental study was conducted with two cultivars of soybean (Viking 1832 and Viking 1706) to provide additional information on crop allelopathy. Five field pea cultivars from two distinct leaf types were chosen to determine competitive ability against weeds. Results indicated that semi-leafless cultivars (Cooper and Golden) had better plant establishment than normal leaf type (PS07100091, NDP080106 and NDP080102). Based on the results, these two semi-leafless cultivars could be considered more competitive against weeds. Results from the greenhouse study also indicated the superiority of a semi-leafless cultivar. Future studies need to be done to determine other morphological traits that make pea plants more competitive against increased weed pressure.

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"In a day, when you don't come across any problems - you can be sure that you are travelling in a wrong path" – Swami Vivekanand. This quote seems true about our research. We have faced many problems due to bad weather conditions. In spite of these difficulties, we made this research successful. This research would not have been possible without the guidance of several individuals who in one way or another contributed and extended their valuable support in the completion of this study.

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INTRODUCTION

Plant Interference

Plant interference is a broad phenomenon, encompassing a wide range of interactions that occur among individual plants when they grow in close proximity (Burkholder, 1952). According to Vandermeer (1989), crop-weed interference is a double transformation process, whereby one plant transforms environmental variable that subsequently transforms another plant; thus, two individual plants interact indirectly through the environment. These indirect changes usually affect either resource availability or microclimatological variables, such as temperature or wind speed (Harper 1977).

Plant interactions can be positive, negative, or neutral (unaffected) for each individual. Competition, amensalism, and parasitism represent three types of interactions where at least one interacting individual plant experiences a negative effect. With competition, both interacting individuals have mutually negative effects on each other (Barbour et al. 1987). Amensalism is a type of interaction in which one plant is unaffected and the other is harmed (Barbour et al. 1987). Allelopathy is a form of amensalism (Radosevich et al. 1997) where exudation of chemical compounds by one individual plant has either direct or indirect negative effects on another individual plant. Competition involves the depletion of resources from the environment, whereas allelopathy refers to addition of a chemical compounds to the surrounding environment (Rice 1984).

Better understanding of crop-weed interactions can provide weed management options that optimize yield while reducing production costs (Mohler and Staver 2001). The main focus of the current research was to determine if field pea cultivars varied in weed suppression ability under organic cropping systems. A secondary objective of this thesis was to determine the

allelopathic capacity of two soybean (*Glycine max* L.) cultivars. The knowledge gained from this research will help organic producers use crop competitive and allelopathic abilities when developing cropping systems that are resistant to the adverse effects of weeds. Therefore, this literature review will focus on discussing crop-weed competition and allelopathy in the context of field crop production**.**

Crop-Weed Competition

Competition is a mutually negative interaction between two individual plants that require the same limited resources, such as nutrients, water and light. When two such individuals grow in close spatial proximity, competition for limited resources leads to a reduction in survival, growth or reproduction of both individuals (Harper 1977). Competition between individual plants is often asymmetric, whereby the larger individual extracts a disproportionate share of the resources and suppresses the smaller individual. Thus, larger plants often have a competitive advantage over smaller plants (Firbank and Watkinson 1987). For example, plants germinating earlier will have a greater advantage over smaller, later emerging individuals (Black and Wilkerson 1963, Howell 1981). Relative emergence time strongly influences competitive outcomes between crops and weeds (Weiner et al. 2008). When crop plants emerge before weeds, they can extract more resources from the surrounding environment than later emerging weeds, which will give the crop a competitive advantage that leads to asymmetric competition (Wilson 1988). On the other hand, with symmetric competition, both large and small individuals have effects proportionate to their respective size (Weiner 1990). Competition for light is often asymmetric because it occurs only when one plant is large enough to shade another, but competition for soil nutrients is usually symmetric and occurs just after germination (Weiner 1986).

Importance of highly competitive cultivars for organic systems

Weed competition is often a critical factor limiting crop yield in organic production systems and, because the use of synthetic herbicides is prohibited, cultural weed management options are crucial to maintaining adequate yield. According to McDonald (2003), growing competitive crop cultivars can reduce reliance on herbicides because competitive crop cultivars better tolerate and suppress weeds (Jordan 1993). Choice of crop cultivar can, therefore, be an important aspect of limiting yield loss due to weeds in organic systems. The process of identifying highly competitive cultivars should be based on high weed suppression ability and competition tolerance. Weed suppression ability of a cultivar is its ability to reduce weed growth, seed production, and seedling establishment (Hoad et al. 2008). Tolerance of a cultivar to weed pressure is its ability to maintain yield consistently when weeds are present in the system (Goldberg 1990).

Many of the problems in organic production of field pea (*Pisum sativum* L.) are related to weed management (Moynihan 2010). Field pea has relatively slow growth during the early season, which makes it a poor competitor with weeds (McKay et al. 2003). For example, two wild mustard (*Brassica kaber* L.) plants per square foot can reduce pea yield between 2 to 35 percent (Wall et al. 1991). Choosing a highly competitive pea cultivar, along with refining other management practices such as cultivation, mulching, burning, and grazing, could help decrease pea yield loss due to weeds (McKay et al. 2003). However, due to the lack of research on highly competitive field pea cultivars, weeds remains a serious problem in organic systems (Murphy et al. 2007).

Influence of morphological traits on crop competitive ability

Morphological and physiological differences can contribute substantially to the competitive ability of a crop cultivar (Lemerle et al. 2001). These traits are controlled by genetic as well as environmental factors. Under conventional management, short cultivars have an advantage over tall cultivars because resource partitioning favors grain yield over vegetative growth (O'Donovan et al. 1997). Thus, many crop cultivars have been bred for dwarf stature. But in organic systems, dwarf cultivars may not be desirable because short stature can limit competitive ability against weeds. The shortest cultivar in wheat (Triticum spp.) was associated with the largest reduction in yield because the shorter canopy allowed vigorous weed growth in previous research under organic management (Huel and Hucl 1996).

Several other morphological factors determine the competitive ability of a crop, including early vigor, growth rate, biomass, leaf area, leaf angle, crop density, and tillering capacity in grass crop (Grace 1990). For example, Lemerle et al. (1996) reported that tillering capacity confers great competitive ability in wheat in addition to many other competitive traits such as height and canopy structure. Hence, the evaluation of different morphological traits involved in competition can provide an understanding of crop-weed dynamics which can result in yield increase of crops grown in organic systems, because, as with many crops, competitive ability is largely controlled by genotypic constitution and associated morphological traits (Caton et al. 2003; McDonald et al. 2003).

Factors determining field pea competitive ability

Leaf type is a key morphological trait that may influence the competitive ability of field pea. Morphologically, there are three types of growth habit of field pea cultivars: normal leaf, semi-leafless, and leafless (Zohary and Hopf 2002). Since leafless cultivars are not usually

grown, this discussion focuses on the semi-leafless and normal-leaf types. Normal type peas have pinnately compound leaves and vine lengths ranging from 0.9 m to 1.8 m. (Zohary and Hopf 2002). This type of pea has an indeterminate type of growth habit, and is late-maturing (90 to 100 days to harvest). The stems of normal leaf cultivars are compact and stronger than those of semi-leafless cultivars (Beeck et al. 2006). Normal-leaf indeterminate cultivars have demonstrated yield stability under heat and moisture stress (Stelling 1994). Therefore, normal leaf peas are often more suitable for production in regions that experience high mid-summer temperatures coupled with frequent drought.

Semi-leafless pea cultivars have one or more leaflets and a shorter vine length of 0.6 to 1.2 m. Semi-leafless types produce more tendrils, which increases interplant connectivity and stability for efficient crop harvesting (Armstrong et al. 1994). This is important because pea lodging at early stages reduces photosynthetic efficiency and final yield and causes crop harvesting difficulties (White and Hill 1999). Semi-leafless peas have a determinate type of growth habit and mature in 80 to 90 days. Semi-leafless cultivars also form relatively open canopies that are less conducive to fungal pathogens, which negatively impact pea production (Cote et al. 1992). Therefore, semi-leafless pea cultivars are more suitable for areas with greater rainfall.

Semi-leafless cultivars have improved standing ability compared to normal-leaf cultivars due to their strong stem (Heath and Hebblethwaite 1985). Pullan and Hebblethwaite (1990) found that irrespective of leaf type, seed yield can be increased by selecting a field pea cultivar with lodging resistance. Lodging resistance of semi-leafless cultivars is a preferred trait in organically managed cropping systems, but the lower growth rate of semi-leafless cultivars requires a greater seeding rate compared to normal-leaf cultivars.

Total amount of photosynthetic radiation interception is one important determinant of biomass production (Georgieva et al. 2000); therefore, light often plays a substantial role in crop competitiveness. The photosynthetic activity of the tendrils is less than that of the leaves (Pyke and Hedley 1985). Semi-leafless cultivar canopies are largely composed of tendrils which have less photosynthetic leaf area compared to canopies of normal- leaf cultivars. Greater planting density can help offset lower yield of semi-leafless cultivars due to reduced interception of light radiation (Heath and Hebblethwaite 1984).

Along with inherent morphological traits, canopy development is critical to crop competitive ability (Ayaz et al. 2004). One factor that has great influence on canopy development is plant density (Ayaz et al. 2004). Economic plant density is optimized when maximum economic return could be achieved, considering various costs of inputs. In other words, optimum economic plant density is a point on the yield curve where an increase in yield is not compensated by the extra seed cost incurred (Heath and Hebblethwaite 1987). Optimal plant density is based on several considerations such as growing purpose (forage, grain, or cover), plant genotype, and climatic conditions (Davies et al. 1985). The current recommended seeding rate for field pea in an organic cropping system is 88-90 plants m^{-2} (Saskatchewan Pulse Growers 2006). Previously, a higher sowing rate of 90-120 plants m^{-2} was recommended in New Zealand for horticultural field pea production (Bussel et al. 1983). These rates were determined by researchers to provide maximum economic returns. Higher sowing rates are recommended for organic production systems due to increased weed pressure (Johnston et al. 2002). This fact is especially true for semi-leafless cultivars, which have comparatively shorter vine length than normal-leaf cultivars.

To achieve the targeted plant density, three things must be taken into account: seedling mortality, seed size, and seedling vigor. Seedling mortality refers to the survival of seed in different soil types under different environmental conditions (moisture and temperature), which are difficult to estimate ahead of time (Johnston et al. 2002). Higher temperature and lower moisture levels lead to germination losses (Meadley and Milbourn 1970). Seedling rate adjustments must be made to account for germination losses. Seed size (mass) and seedling vigor are key determinants of germination success (Erikson 1999; Turnbull et al. 1999). For instance, previous studies on chickpea showed a positive correlation between seed size and seedling vigor (Murray and Auld 1987). Semi-leafless pea cultivars had greater seedling vigor and had better stand establishment than normal-leafed cultivars under poor germination conditions because of larger seed size (Uzun and Acikgoz 1998). Early vigor promotes early emergence which results in quick canopy closure and greater interception of incoming solar radiation (Uzun and Acikgoz 1998). Both normal leaf and semi-leafless cultivars demonstrate different yield density relationships (Heath and Hebblethwaite 1987). According to Uzun and Acikgoz (1998), normal leaf cultivars produce less seed yield at greater densities, whereas per unit area yield of semi-leafless cultivars increases with greater plant densities of 110 plant m^{-2}. Seed yield of normal leaf cultivars tends to decline at densities above 75 plants m^{-2}, while yield of semi-leafless cultivars is maximized at around 100 plants m^{-2}.

Methods to study crop-weed competition

Plant competition can be evaluated in mixed stands using additive, replacement, Nelder, and neighborhood designs (Cousens 1991). In an additive experiment, crop density remains constant, while the density of the weeds varies. This is also true under field conditions where crop density is fixed and effect of increasing weed density will have an additive effect on yield

loss (Harper 1977). Thus, additive design is an appropriate method to study competition in a field settings (Radosevich 1987).The major problem of this experimental approach is the difficulty in differentiating between intra- and inters- specific effects, so the result provides only a crude picture of competition (Connolly 1986).

Most of the criticism against additive experiments can be overcome using a replacement series design (Jolliffe et al. 1984). In this design, two species are grown together at constant densities in varying proportions along with each in monocultures. The yield of the monoculture is compared that of the mixed population. The replacement series is not appropriate for agronomic settings where understanding the effect of varying densities on inter-specific competition is the key concern. The Nelder design is often referred as a systematic method because the plant density and spatial arrangement changes systematically (Neldar 1962). These design consists of grid of plants, planted in arc or in circular pattern. The amount of space available to each plant within a grid changes consistently. The advantage of using this design is that a combination of densities can be studied without any change in plant arrangement. However, interference can be evaluated only among individuals of single species using this method.

The neighborhood approach considers a target plant in association with other plants within a fixed radial area around the target plant. The fixed area is called a neighborhood radius and has the greatest influence on target plant overall performance (Pacala and Silander 1990). Therefore, distance between the neighbors and overall spatial configuration is an important factor in this type of crop-weed competition study (Stoll and Weiner 2000); the local environment decides the fate of a plant to a large degree. This type of study can be conducted in a controlled environment (Pacala and Silander, 1987) or in the field (Bussler et. al. 1995).

The classical methods of studying crop-weed competition do not account for weed suppressive ability and tolerance of competition. Also, these approaches require establishment of many experimental plots with precise content and spatial arrangement of competing plants. This requirement is not too onerous when evaluating the competitive ability of one crop variety against one weed species. However, for studies aimed at evaluating competitive abilities of many crop cultivars against a wide range of weed species, these types of designs are too difficult to establish and time-consuming to manage. Moreover, these designs often do not reflect realistic field production conditions. An alternative, more manageable and realistic approach to evaluating crop cultivar competitive ability was developed by Hoad et al. (2008), who evaluated the competitive ability of several wheat cultivars in an organically managed cropping system.

According to Hoad et al (2008), the sensitivity of crop cultivars and their ability to suppress weeds in response to changes in weed pressure and/or density provides a way to gauge relative competitive ability among various cultivars. The evaluation of both weed suppressive ability and sensitivity of this ability across different levels of weed growth/ populations has considerable potential for selecting suitable cultivars for organic pea cultivation. The most competitive cultivar will be the one with both high weed suppression ability and low sensitivity (high stability in suppressive ability over a range of weed densities).

As explained by Hoad et al. (2008), weed suppressive ability can be determined by the amount of endemic weed cover reduced by the presence of the crop. To calculate weed suppressive ability, weed growth is determined at each critical crop growth stage by evaluating the percentage ground cover of the endemic weed population when viewed from directly above. Two measurements are required: the percentage of weed ground cover when grown with a crop cultivar (W_{var}) and the weed percentage ground cover in a weedy check composed of endemic

weeds only. The weedy check provides an estimate for unrestricted weed growth (W_{max}). Weed suppressive ability of each cultivar (S_{cul}) is calculated as the percentage reduction in weed cover in crop plots compared to unrestricted weed growth in the weedy check.

Another important component of competitive ability is the sensitivity of cultivars weed suppressive ability to changing levels of weed pressure or weed density. Hoad et al. (2008) determined this sensitivity as the slope of a linear regression of S_{cul} against $W_{max.}$ A large positive or negative slope signifies low stability in weed suppressive ability of a particular cultivar (S_{cul}) and vice-versa. With this approach, two cultivars having the same weed suppressive ability could differ in sensitivity to changes in weed growth. The rationale behind evaluating the sensitivity across different growth stages of weeds and different weed pressure is to provide a clear picture of competition across different locations with different weed populations.

These two measures of competitive ability provide a valuable tool for cultivar evaluation in organic agriculture across a range of favorable and unfavorable conditions. There could be a cultivar which maintains high yield at low weed pressure, but cannot maintain ever moderate yield level if weed pressure is increased only slightly. This cultivar is highly sensitive to change in weed pressure, which is undesirable, particularly in organic agriculture because use of most of the synthetic chemicals is prohibited. Choosing the most competitive cultivar could be more risky if cultivars are highly sensitive to changes in weed pressure. In organic agriculture, where weed pressure is often high, the best cultivar will be one with high weed suppressive ability over a wide range of weed densities. This approach is particularly well suited to evaluating numerous cultivars under organic management because the use of weed-free checks, which would be extremely difficult to achieve in organic plots, is not required.

Allelopathy

Under some circumstances, the negative effects of one plant upon its neighbor are so profound that competition for common resource pools is not sufficient to explain the outcome (Weston 2005). Allelopathy is one type of interference that may sometimes contribute to such observations (Weston 2005). Allelopathy is a biochemical phenomenon that occurs when a chemical produced by one plant species has inhibitory and/or stimulatory effects on another plant species (Molisch 1937, Rice 1984). Allelopathy is a broad term that includes direct and indirect effects of exuded chemicals on a target plant (Weston 1996). Exuded chemicals are secondary metabolites, known as allelochemicals that, upon release, affect the growth, survival and reproduction of target plants. Direct allelopathic effects are mediated via allelochemicals which directly impact the target plant regardless of the surrounding abiotic or biotic environment (Inderjit and Weiner 2001). Indirect allelopathic effects are mediated by biotic factors such as microorganisms and lower plants that metabolically transform plant compounds into chemical forms that are often detrimental to the target plant (Dakshini et al. 1999). For example, microorganisms sometimes convert certain plant exudates into active allelochemicals via metabolic biochemical processes (Putnam and Tang 1986; Rice 1984). Another indirect effect is suppression of nodulation in legume crops by allelochemicals (Batish et al. 2007).

Allelochemicals can be present in almost any plant part, including roots, stem, leaves, flower, bark, and buds (Weston and Duke 2003). Allelopathic effects are influenced by genotype, environment, growth stage of the producing plant, and microbial degradation of the compound in the soil rhizosphere (Belz 2007). Dakshini et al. (1999) used the term "allelochemical interaction" to represent the effect of allelochemicals on biotic and abiotic components of the rhizosphere. Biotic and abiotic factors (insects, heavy metals, weak solar

radiation, reduced nutrient, and increased temperature) have also been shown to induce allelopathy in crops. For example, exudation of three major allelochemicals by two cultivars of rice (*O. sativa*) was induced due to presence of the weedy species barnyardgrass (*E. crusgalli L.*) (Kong et al. 2004, Zhao et al. 2005). Therefore several methods have been introduced to study the allelopathy and allelopathic interaction.

Methods to study allelopathy

Separating allelopathic effects from other forms of plant interference such as competition is very difficult under any circumstances (Radosevich et al. 1997). According to Putnam and Duke (1978), several problems create difficulties in differentiating general plant competition from allelopathy. These problems include a lack of appropriate design of laboratory bioassays, failure to identify the existence of direct and indirect influence through other organisms, and modification in micro-environmental condition caused by other forms of plant interference.

A wide range of techniques has been adopted to study allelopathy. Most of these techniques involve chemical isolation of putative allelochemicals, followed with bioassays to determine phytotoxicity (Rizvi and Rizvi 1992). Organic solvent extraction and cold-water infusion are used for the isolation of toxins (Bonner and Galston 1944; Radosevich et al. 1997). Additionally, more straightforward studies have been conducted using crop residues incorporated directly into gravel based plant culture (Gaidmak 1971). Another approach is to add putatively allelopathic crop residues to soil for an extended period of time and then bioassay the soil for allelochemical activity (Weston 2005). Allelopathy can also be assessed using the equal compartment agar method for detection of inhibitory root exudates (Wu et al. 2000). Tang and Young (1982) developed a new technique in which putatively allelopathic plants and target plants are grown separately in plastic pots and then soil water solution is circulated between the

pots through a connecting tube. An exchange column is inserted between the allelopathic and target plant that adsorbs the active chemical from the root exudate. This active compound can then be isolated and bioassayed for phytotoxicity. With the increasing sophistication in chemical detection techniques, significant process has been made in detection and identification of allelochemicals (Putnam and Tang 1986). An important point to note is that, to be considered allelopathic, allelochemicals should be present in soil at phytotoxic concentrations (Weston 1996). Many of the methods used to determine potential allelopathy do not take this factor into account. Also, approaches that exclude soil in the study, neglect many biophysical and biochemical effects that the rhizosphere exerts to determine allelochemical activity (Blum 1995).

Use of allelopathy for weed suppression

For the last 30 years, scientists have debated the potential role of allelopathy in agriculture (Rice 1984; Singh et al. 2003; Weston 1996). Most previous research focused on extraction and evaluation of plant secondary metabolites mainly using extract bioassays in the absence of soil. Beginning the 1990's research shifted from sole reliance on laboratory bioassays to incorporation of field studies (Dakshini et al. 1999). This shift was motivated in part because of increasing problems related to herbicide resistant weeds and herbicide residues (Kohli et al. 1998). Increasing public concern about environmental issues and subsequent expansion of organic agriculture opened the way for more research on the allelopathic potential of crops (Singh et al. 2003). Various studies have been conducted to explore the use of allelopathic cover crops, intercrops, and rotational crops for weed suppression (Putman 1978). Allelopathy may be a viable component of weed suppression in organic agriculture. Also, this phenomenon may have a small role to play in reducing weed pressure in other types of production systems where the producer seeks to reduce the costs and potential negative environmental effects associated with

synthetic herbicides (Bond and Grundy 2001). There is a need to evaluate different crop cultivars that are inherently weed suppressive. Traditional breeding approaches are mostly concerned with increasing yield, quality and disease resistance, and variation in allelopathic effects is seldom considered (Weston 2003). Many studies on allelochemical biosynthesis indicate multigenic regulation of allelochemical traits. Hence, using genetic engineering techniques to breed an allelopathic crop is not straightforward.

Studies have been performed to evaluate the weed suppressive ability of contrasting cultivars of winter wheat cultivars (*T. aestivum* L.), barley (*Hordeum vulgare* L.) and sunflower (*Helianthus annuus* L.) (Bertholdsson 2004; Rice 1984). Winter rye (*Secale cereal* L.) residues had inhibitory effects on annual broadleaf weeds reduced weed biomass up to 75 % (Moyer et al. 2000). Nagabhushana et al. (2001) reported even greater suppression of early season broadleaf weeds by rye residue up to 98 %.

Tests of oleander (*Nerium oleander* L.) allelopathic effects on maize showed that weed density decreased and maize (*Zea mays* L.) yield increased compared to a weedy check having equal densities of different weeds (Uygur and Iskenderoglu 1997). The allelopathic effect of oleander root, stem, leaf, and bud extract has been tested for negative effects on green bean (*Phaseolus vulgaris* L.) and wheat germination and early seeding growth. These plant part extracts had more negative effects on bean than wheat. Oleander bud extract was more allelopathic against bean than against wheat seedling growth, but oleander root extracts were very effective against early seeding growth of wheat and bean (Uygur and Iskenderoglu1997). Another example of allelopathy is in garden radish (*Raphanus sativus* L.), which reduced the Johnsongrass (*Sorghum halepense* L.) emergence by 99.7% (Uludag et al. 2006). Garden radish inhibits specific weed species while other weeds are not inhibited (Uludag and Uremis 2009).

Alfalfa (*Medicago* Spp.) has strong allelopathic effects against Russian knapweed (*Acroptilon repens* L.) (Abbassi et al. 2012). Alfalfa decreases mugwort (*Artemisia vulgaris* L.) infestation up to 89 % under field conditions and alfalfa extract inhibited mugwort germination up to 83 % in petri dish assays (Onen 1999).

A study by Bertholdsson et al. 2004 demonstrated the importance of considering older cultivars/germplasm for allelopathic potential associated with early vigor of seed. These older cultivars tended to establish early (because of early vigor) and also suppress weeds during the growing season (Bertholdsson 2004). Newer cereals cultivars tend to have high yield potential but very low weed suppressive ability because of many available options of control weed problem (Bertholdsson 2004). Therefore, evaluating older cultivars for high weed suppressive ability due to allelopathy and/or competition is often necessary or advantageous (Bertholdsson 2004).

Negative effects of allelopathy

Worldwide, many ecosystems are currently threatened by invasive plant species that create vast monocultures, outcompeting native vegetation (Weston and Duke 2003). A few successful plant invasions have been associated with allelopathic effects including Japanese knotweed (*Polygonum cuspidatum* L.), garlic mustard (*Alliaria petiolata* L.) and Centaurea species (Beerling et al. 1994, Furtuna et al. 2002). Allelopathy is thought in some instances to allow a plant species to invade and establish an undesirable monoculture pattern (Bais et al. 2003). For example, garlic mustard spread rapidly across 36 states in the US and formed monotypic stands due to allelopathic effects (Weber and Gibson 2007, Welk et al. 2002). Invasion of garlic mustard took place due to indirect inhibition of the growth of symbiotic mycorrhizal fungi (McCarthy and Hanson 1998). These symbiotic mycorrhizal fungi play a

substantial role in nutrient uptake (especially phosphorous) that other plants require for normal growth (Stinson et al. 2006; Wolfe et al. 2008). Japanese knotweed is also thought to have established invasive monocultures because of a unique set of allelochemicals produced by the roots of this species (Kimura et al. 1983).

Spotted knapweed (*Centaurea stoebe* L.) has established large monocultures in North America and throughout Great Britain. Recent research showed that spotted knapweed contains catechins, a class of compounds that sometimes have anti-microbial and phytotoxic properties (Bais et al. 2002) and are putatively responsibly for allelopathic effects. These allelochemicals kill the root system of plant through reactive oxygen species that also interfere with the gene expression (Bais et al. 2003). However, research by Blair et al. (2006) concluded that potential toxicity of catechins is regulated by soil moisture. Degradation or retention of catechin depends on the soil moisture content; therefore, soil moisture plays an important role in phytotoxity of this allelochemical. Initially, researchers assumed that (–catechins) is more potent than (+ catechins) and that the allelopathic effect is caused by oxidative stress to the plant through a series of chemical reactions. Research conducted by Duke et al. (2009) refuted this idea and proved that the (+) and (–) catechins are equally potent and do not cause oxidative stress. These conflicting research results demonstrate the difficulty of understanding the underlying mechanisms of putative allelopathic interactions.

Limitations of allelopathy

Integration of allelopathic effects into a weed-suppressive cultivar via genetic engineering techniques is not an easy task. Environmental and genotypic interactions that regulate the allelochemical production make such research very complex (Weston and Duke 2003). More research is needed to understand the mode of allelochemical selectivity, mode of

action, and genetic regulation of biosynthesis of allelochemicals (Belz 2007). One has to consider the level of efficacy and reliability of these phenomena for better crop management (Belz 2007). Rice is the first crop where two traits, increased competitive ability and allelopathic effects, were integrated and commercialized (Olofsdotter 1998). But whether this allelopathic cultivar improves crop yield remains questionable. One reason is there is a strong chance that increasing allelopathic potential or competitive ability could change plant physiology, resulting in a profound effect on plant yield or tradeoff between the yield and competitive abilities (Belz 2007 and Olofsdotter, 2002). According to Gealy et al. (2003), combination of these two traits cannot automatically insure adequate weed control and yield protection. Nevertheless, there is a need for broad collaboration between agronomists, weed scientists, plant physiologists, and molecular geneticists to develop weed suppressive cultivars for use as part of an integrated weed management strategy (Gealy et al. 2003). As competition works in conjuction with allelopathy, there is a need to improve both simultaneously to achieve maximum weed suppression under organic agriculture (Olofsdotter et al. 2002).

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CHAPTER 2. FIELD PEA (*Pisum sativum* L.) COMPETITIVE ABILITIES FOR WEED SUPPRESSION IN ORGANIC AGRICULTURE

Abstract

The objective of this study was to determine the competitive ability of different field pea cultivars against endemic weed populations present in organic cropping systems. Five field pea cultivars representing two distinct leaf types (normal and semi-leafless type) were chosen to evaluate field pea competitive ability against weeds. Weed suppressive ability was calculated at each growth stage, as well as the sensitivity of weed suppressive ability to changing weed pressure. Results showed that Cooper and Golden had better plant establishment than other three cultivars, even under poor germination conditions. Cultivars with low seedling mortality and good emergence were considered more competitive. Cooper and Golden had good emergence because of inherent seed vigor, which is probably a function of greater seed size. Thus, these two semi-leafless cultivars could be considered as more competitive cultivars, because they are more likely to form even competitive canopies under a wide range of environmental conditions.

Introduction

Field pea (*Pisum sativum* L.) is an important annual cool-season pulse crop that is commonly used for direct human consumption and livestock feed (Cousin 1997). Field pea fixes nitrogen biologically from the atmosphere, which makes it useful as both an alternate and rotational crop in organic production systems (Zimdahl 2004). Field pea production in the United States was initially concentrated in the three states: Washington, Oregon, and Idaho (McKay et al. 2003). However, US field pea production has expanded in recent years. North Dakota and Montana which currently are the two leading pea producing states domestically (McKay et

al.2003). Harvested acreage of field pea totaled 315,000 acres in Montana and 235,000 acres in North Dakota (NASS/USDA 2012).

Many of the problems in organic field pea production are related to weed management (Moynihan 2010). Field pea has relatively slow growth during the early season, which makes it a poor competitor with weeds (Harker 2001). Choosing highly competitive pea cultivars could help decrease pea yield loss due to weeds (Zimdahl 2004).

Leaf type is a key morphological trait and may influence competitive ability of field pea. Normal and semi-leafless growth forms are two agronomically viable field pea types. Normal leaved pea cultivars have an indeterminate growth habit as well as demonstrated yield stability under heat and moisture stress (Stelling 1994). Semi-leafless cultivars have indeterminate growth with more open canopy structure, which makes this type more suitable for areas with greater rainfall, where plants are more prone to disease and insects (Cote et al. 1992). Semi-leafless cultivars have improved standing ability than normal leaved cultivars due to intertwining of leaflets that terminate in tendrils (Heath and Hebblethwaite 1985). Greater seed size of semi-leafless cultivars provides competitive advantage over normal leaf type at two leaf stage. Greater seed size increases seedling vigor and lowers seedling mortality, leading to better crop establishment (Murray and Auld 1987).

Replacement series, additive, and neighborhood designs are used to evaluate plant competition. However, these approaches have problems differentiating intra- and inter-specific competition. Also these approaches require many experimental plots with precise spatial arrangements that are time-consuming to establish and maintain. Hoad et al. (2008) developed a more manageable approach to evaluate plant competitive ability which is less time consuming and easier to establish. Using the Hoad methodology, weed suppressive ability and sensitivity of

this suppressive ability across different weed densities can be calculated. Weed suppressive ability of each cultivar (S_{cul}) is calculated as the percentage reduction in weed cover in crop plots compared to unrestricted weed growth in the weedy check, W_{max}. Sensitivity of weed suppressive ability is determined by the slope of linear regression of S_{cul} against maximum weed cover in weedy checks (W_{max}). As reported by Steinmaus and Norris (2002), leaf area index (LAI) is an appropriate index for evaluating the crop competitiveness and can be substituted for visual estimates of the relative cover that are used in the calculation of weed suppressive ability by the method given by Hoad et al. (2008). Thus LAI was used instead of visual estimates of relative cover for this study. This approach can be used for screening the competitive ability of many crop cultivars against a wide range of weed species.

Lack of research on identifying competitive cultivars contributes to weeds remaining a serious problem in organic pea production systems (Murphy et al. 2007). Research aimed at evaluating field pea cultivars for competitive ability against weeds in certified organic fields in the Great Plains, including North Dakota, may provide growers with highly competitive cultivars that are adapted to high endemic weed pressure (Murphy et al. 2007).

I hypothesized that due to increased leaf area, normal-leaf cultivars would have greater weed suppressive ability against endemic weeds than semi-leafless cultivars. The objective of the proposed research was to determine which of two semi-leafless and three normal-leaf pea cultivars was most competitive against weeds in a North Dakota organically-managed cropping system. The specific objectives were to: 1) determine weed suppressive ability and sensitivity of weed suppression to changes in weed pressure for five field pea cultivars competing against endemic weed populations in organically managed ND cropping systems; and 2) quantify the

competitive effect of common lambsquarters (*Chenopodium album* L.) against one normal-leaf cultivar and one semi-leafless pea cultivar grown under controlled greenhouse conditions.

Materials and Methods

Objective 1: Field study for evaluating field pea competitive ability

Field experiments were conducted during summer 2011 and 2012 at the Dickinson Research Extension Center (DREC, 46.895° latitude, 102.813° longitudes), ND. In 2012 only, a field experiment was conducted at Carrington Research Extension Center (CREC, 47.509° latitude, -99.132° longitudes). Three field runs of the experiment were conducted, in total. The soil at the DREC farm site used in 2011 was Reeder-Farnuf loams; USDA classification – Fine-loamy, mixed, superactive frigid Typic Argiustolls, soil test (prior to 2010 season; no soil test taken in 2011): NO_3-N = 18 lb/acre (0 to 1 ft depth), 15 lb/acre (1 to 2 ft depth); P = 16 ppm, SOM = 2.2% (0 to 6 inches), pH = 6.8 (0 to 6 inches). No K soil test because soils historically test very high in K. 2012: Arenegard loam (0 to 2% slope); USDA classification – Fine-loamy, mixed, superactive frigid Pachic Haplustolls, soil test (prior to 2010 season; no soil test taken in 2011 or 2012): NO_3-N = 18 lb/acre (0 to 1 ft depth), 2 lb/acre (1 to 2 ft depth), 4 lb/acre (2 to 3 ft depth); P = 14 ppm, SOM = 2.4%, pH = 5.7. No K soil test because soils historically test very high in K. The soil at the CREC farm in 2012 is classified as Heimdal-Emrick loam having pH 6.2. Five field pea cultivars/lines (Cooper, CDC Golden, PS07100091, NDP080106 and NDP080102) representing two different market classes (yellow and green) (Table 2.1) were selected to evaluate for competitive abilities against weeds. Two of these cultivars (Cooper and CDC Golden) have an upright growth habit with a semi-leafless structure, lodging resistance, and good agronomic adaptation (Table 2.1).

Field peas were planted in a randomized complete block design with four replications. Each replication included a crop-free plot (weedy check) to assess maximum potential weed emergence and growth. Germination tests were conducted before seeding so that optimal pea densities (88 plants per square meter) could be achieved.

Table 2.1. Morphological characteristics of field pea cultivars.

Cultivar	1000 seed wt (g)	Cotyledon color	Seed coat color	Leaf type
PS07100091	270	Yellow	White	Normal
NDP080106	272	Green	White	Normal
NDP080102	210	Green	White	Normal
CDC Golden[†]	294	Yellow	White	Semi-leafless
Cooper	370	Yellow	White	Semi-leafless

[†]CDC Golden was grown only during 2012.

Field peas were sown at DREC on 9 May 2011 and 16 April 2012, while at CREC peas were seeded on 1 May 2012. Plot dimensions were 4.5 by 3.6 m. The seeding rate was 237 kg ha $^{-1}$ for PS7100091 and NDP 080106; 184 kg ha $^{-1}$ for NDP080102 and 325 kg ha $^{-1}$ for Cooper. Four cultivars were seeded in 2011 whereas one extra cultivar (CDC Golden) was seeded at the rate of 220 kg ha $^{-1}$ at both locations in 2012. Whole plot pea emergence was quantified at the 2 to 3 node pea growth stage. After full emergence, three permanent quadrats of 0.25 m^2 centered on two rows of peas were established in each plot for destructive and nondestructive measurements of pea and weed growth. In each quadrat, approximately 22 plants of field pea were maintained as per the recommended seeding rate under organic agriculture. In some instances, field pea emergence was poor and 22 plants per quadrat could not be achieved. In

these plots, quadrats were established to contain the greatest possible density and pea density within each quadrat was quantified so that measurements could be adjusted to a per plant basis.

To assess relative cover of weeds and field pea, canopy light interception /LAI measurements were conducted within permanent quadrats using a PAR/ LAI ceptometer (AccuPAR model LP-80, Decagon Devices). Ceptometer probe length was 84 cm and leaf distribution (x) was set at 0.87. Two measurements were taken diagonally in each quadrat for LAI. These measurements were made prior to destructive harvests at critical field pea growth stages (2-3 nodes, 6-8 nodes, and onset of flowering) to quantify pea and weed canopy development.

At each critical growth stage, total canopy LAI (weed + pea) was measured in one of the permanent 0.25 m^2 quadrats in each plot. Pea shoot biomass was then carefully removed from each quadrat and the weed-only LAI was measured. These measurements provided a measure of separated weed and pea LAI in each plot at each critical pea growth stage. Weed LAI was also measured in the weed-only plots at the same points in time and weed shoot biomass was subsequently harvested. Weed and pea shoot biomass were dried to a constant weight at 80°C for 72 hours. On the third and final destructive harvest date, pea pod number and final grain yield were determined from destructive quadrat-level measurements. Final pea grain yield was adjusted to a per plant basis for analysis because of variable pea densities in the quadrats. Lodging ratings were taken prior to the harvest on percentage basis, with 0% indicating no lodging, 50% indicating that pea stems were bent at a 45 degree angle, and 100% indicating that pea stems were bent horizontal to the ground. Finally remaining pea plants in plots were harvested at full senescence with a plot harvester on 03 September 2011 and 23 July at DREC and 4 Sep at CREC in 2012.

Weed suppressive ability (S_{cul}) and sensitivity of suppressive ability to changes in weed pressure were calculated according to Hoad et al. (1998). Weed growth or cover was quantified by leaf area index measurements of weeds in the weed check plots as well as the weeds grown with various pea cultivars. Weed suppressive ability of each field pea cultivar was calculated as percentage reduction in weed LAI of each cultivar with respect to maximal weed LAI from the uncropped weedy checks located in each block (Hoad et al. 1998); i.e., weed suppressive ability was calculated via equation 1, where LAI W_{max} is the leaf area index for the weedy check and LAI_{var} is the weed leaf area index in cropped plots.

$$S_{cul} = \frac{\text{LAI } W_{max} - \text{LAI}_{cul}}{\text{LAI } W_{max}} \times 100$$

For each destructive harvest, S_{cul} values for each plot/pea variety were linearly regressed against weed LAI values from each cropped plot to calculate the sensitivity of each cultivar to changes in weed density. Sensitivity of each cultivar is the slope of the regression line that signifies the competitive abilities of a cultivar against changing weed pressure. A large regression coefficient (slope) indicates that a cultivar has high sensitivity/low stability and would perform relatively poorly at high weed pressure, whereas a small regression coefficient would indicate low sensitivity/high stability at W_{max}.

Fixed effects of field pea cultivar and sampling period, as well as the interaction of these two effects on number of pea plants per quadrat, weed LAI, per plant pea LAI, weed and pea shoot DM, and weed suppressive ability (S_{cul}) were tested via analysis of variance (ANOVA) using Proc Mixed (SAS version 9.3). Fixed effects of pea cultivar on pea grain per plant yield, number of pods per pea plant, and % pea lodging were also assessed via ANOVA. In both cases, replication, site (DREC or CREC) and year were considered random effects. In some instances, one or more random effect was omitted from the model because of problems with zero variance.

For the pea response variable S_{cul}, number of pea plants per quadrat was included as a covariate to account for the differences in S_{cul} that were due to pea density differences. Prior to ANOVA, all data were subjected to diagnostic tests using Proc Univariate (SAS version 9.3). Variance of residuals was assessed via Levene's test to determine homogeneity of variance among site-years and normality was assessed by computing a Shapiro-Wilks statistic. Data conformed to the assumptions of ANOVA and thus were not transformed for analysis. When ANOVA F-tests were significant, means were separated using the ls means statement in Proc Mixed with Tukey's adjustment for multiple posthoc comparisons. When the cultivar x sampling period interaction was significant, means for cultivars within each time period were separated with specific preplanned contrasts. Means were considered different at the 95% confidence level.

Objective 2: Greenhouse study for assessing field pea competitive ability

A controlled greenhouse study was conducted to expand on the results of the field research. For field pea cultivars Cooper and NDP080106, competitive ability against common lambsquarters was evaluated. The greenhouse study allowed for an assessment of comparative response to weed presence for these two cultivars under ideal conditions with non-limiting water and soil nutrients. Cooper and NDP080106 cultivars were chosen because these cultivars have different leaf types (Table 2.1). Common lambsquarters was chosen because it was one of the most problematic weeds at the field study locations.

Three experimental runs of a greenhouse experiment were conducted in September 2011, August 2012, and December 2012 for 95 days. For each experimental run, field peas were planted (3 seeds per pot) and thinned to achieve one plant per pot of 45 (height) x 25 cm (diameter) in a completely randomized design with four treatments levels (pea cultivar + or – common lambsquarters) and four replicates. Four pots were grouped together to simulate field

canopy conditions and were considered an experimental unit. The tendrils of the four pea plants in each experimental unit were allowed to intertwine and interact as pea plants normally would in the field. Because of the way the pots were grouped together, experimental units were rotated on the greenhouse bench periodically to account for microclimatological effects. Common lambsquarters seeds were over seeded around each target pea plant and were thinned after emergence to a density of 12 common lambsquarters plants per pot. Both the field peas and common lambsquarters were planted at same time. Sunshine Professional Natural & Organic Mixes (SUN AGRO Horticulture Company, Grade 1), was used as growth medium. The soil fertility level was adjusted by adding 2.41 g of organic fertilizer product (Slutze company) to each pot to achieve an N fertility level of 29.18 kg ha^{-1}, a value typical of the soil used in the field experiment (based on soil test). A day length of 13 hr was maintained in the greenhouse during the initial growth stages before flowering and thereafter a16-hr day length was maintained by HID (1000W metal halide) supplemental light in the greenhouse. Greenhouse temperature was 14°C for daytime and 10°C during the night time throughout the experiment. Pots were watered manually to field capacity as needed.

Prior to harvest, lodging resistance of pea cultivars was assessed on a 0 to 100 % scale, with 0 % corresponding to no lodging, 50 % corresponding to an 45 degree angle of inclination with the ground, and 100 % indicating that pea stems were horizontal to the soil surface. At pea physiological maturity, pea height, weed height, and pea pod number were measured. Pea and weed shoots were subsequently harvested, pea pods were removed from pea plants, and all plant material was dried to a constant mass at 80 °C. Since pods were removed from the pea shoots prior to drying, measurements of pea shoot dry biomass included only plant vegetative portions.

Treatment effects on pea and weed response variables were tested using analysis of variance via Proc Mixed (SAS version 9.3). Treatment (pea cultivar + or – common lambsquarters) was considered a fixed effect and replication and experimental run were considered random effects. In some instances, due to zero variances issues, one random effect was removed from the model. Prior to ANOVA, all data were subjected to diagnostic tests using Proc Univariate (SAS version 9.3). Variance of residuals was assessed via Levene's test and normality was assessed by computing a Shapiro-Wilks statistic. Data conformed to the assumptions of ANOVA and thus were not transformed for analysis. When ANOVA F-tests were significant, means were separated using the lsmeans statement in Proc Mixed with Tukey's adjustment for multiple comparisons. Means were considered different at the 95% confidence level.

Results and Discussion

Objective 1: Field study for evaluating field pea competitive ability

Environment and pea emergence

During 2011 at the DREC, heavy rainfall was received during May (Table 2.2), which delayed planting and led to poor pea emergence. During 2012, at both DREC and CREC, rainfall during the period when peas were planted and emerging (April and May) was below the ten year average (Table 2.2). Additionally, during 2012, temperature in May and June were above ten year averages for both locations and this may have impacted emergence and early growth because the heat likely dried the top layer of soil where the peas were planted. Thus, during both years, weather conditions were less than optimal for pea emergence. Pea plant density per quadrat varied substantially among pea cultivars, with Cooper achieving maximum density followed by CDC Golden, NDP080102, NDP080106, and PS0710091 (Fig. 2.1).

Pea cultivars varied in ability to germinate and emerge under less than optimal environmental conditions. Cooper and CDC Golden had better plant establishment than the other three cultivars (Fig 2.1). Many studies have established that seed size is directly proportional to seedling vigor (Murray and Auld 1987). Also, the establishment of semi-leafless cultivars (Cooper and CDC Golden) was better than normal leaf cultivars (PS07100091, NDP080102, and NDP080106) (Fig. 2.1). This finding agrees with studies conducted by Uzun and Acikgoz (1998), which showed that semi-leafless cultivars often have better establishment than normal leaf cultivars. The denser stands achieved by Cooper and CDC Golden cultivar are probably attributable to larger seed size compared to other cultivar (Table 2.1).

Table 2.2. Rainfall (mm) measured monthly (April to September) during 2011 and 2012, ten year (2001 to 2010) average rainfall, mean average temperature measured monthly (April to September during 2011 and 2012, and ten year (2001 to 2010) average temperature for Dickinson Research Extension Center and Carrington Research Extension Center. Data are from the North Dakota Agricultural Weather Network (http://ndawn.ndsu.nodak.edu/).

		Rainfall (mm)			Temperature (°C)		
Location	Month	2011	2012	10 yr avg	2011	2012	10 yr avg
Dickinson	April	50.6	48.2	32.5	3.9	8.4	6.34
	May	133.7	49.2	60.6	10.2	12.4	11.5
	June	41.4	56.3	82.2	16.8	18.9	16.9
	July	52.8	38.9	51.8	22.0	24.5	21.8
	August	76.1	31.7	24.3	21.1	20.4	20.5
	September	13.5	3.2	37.4	15.1	15.8	15
	Total	368	227.5	288.8			
Carrington	April	24.7	41.5	23.2	3.4	6.9	6
	May	50.1	50.6	69	11.0	13.1	11.6
	June	87.2	74.5	86.4	17.0	18.6	17.3
	July	156.8	31.3	61.4	21.0	22.3	20.1
	August	132.6	80.7	53.9	20.0	18.2	18.9
	September	59.9	5.6	47.5	13.8	13.2	14.2
	Total	511.3	284.2	341.4			

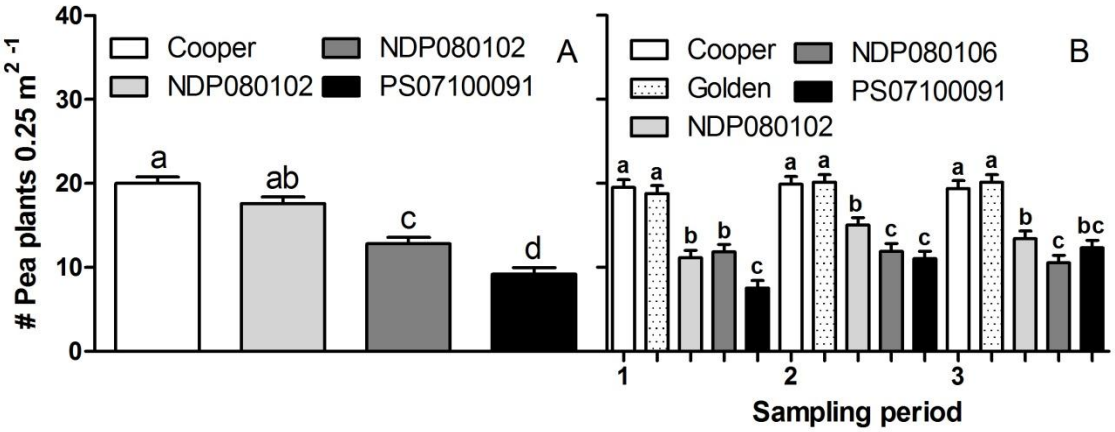

Figure 2.1. Mean ± s.e. number of pea plants per 0.25 m^2 quadrat for (A) four field pea cultivars grown at Dickinson Research Extension Center (DREC) in 2011 (data combined over sampling periods) and (B) five pea cultivars grown at DREC and Carrington Research Extension Center in 2012 (data combined over locations but shown separately for each sampling period). Means designated with different lower case letters differ at a 95% confidence level.

Pea biomass and pea LAI

Because pea density differed among quadrats, pea biomass was assessed on a per plant basis. The ANOVA indicated that pea biomass differed among cultivars (P <0.0001, Table 2.3). A highly significant cultivar by sampling period interaction (P <0.0001, Table 2.3) indicated that pea biomass differed among the cultivars at different sampling periods. The ANOVA indicated that there was a significant effect for pea biomass among cultivar for pea biomass at the first destructive harvest (2-3 nodes) on a per plant basis (Fig. 2.2. C, Table 2.3). CDC Golden had the greatest pea biomass per plant, whereas PS0710091 had the least biomass at the first sampling period. Analysis for all three destructive harvest times indicated that Cooper and CDC Golden had greater field pea biomass as compared to other three cultivars (Fig. 2.2 C). This suggests that these two semi-leafless cultivars (Cooper and CDC Golden) accumulated more plant biomass, in spite of the fact that semi-leafless cultivars usually have approximately 40% reduction in total leaf area (Cousin 1997).

Table 2.3. Analysis of variance results for the F-test and associated P value for field pea leaf area index per plant (LAI/PP), pea dry biomass in gram (PDM), weed LAI (WLAI), and weed dry biomass in gram (WDM) assessed at DREC and CREC in 2011 and 2012. Data were combined across locations and years.

Source	LAI/PP		PDM (gm)		WLAI		WDM (gm)	
	F	P	F	P	F	P	F	P
Cultivar	0.61	0.6569	37.06	<0.0001	4.31	0.0024	21.55	<0.0001
Time	31.76	<0.0001	153.4	<0.0001	154.82	<0.0001	152.8	<0.0001
Cultivar x time	0.690	0.6987	6.64	<0.0001	1.60	0.1289	1.60	0.1289

The biomass production by the pea cultivars suggests that light interception in semi-leafless cultivars, which are mostly composed of tendrils and petioles, is similar to normal leaf cultivars, as was reported by others (Heath and Hebblethwaite 1985). CDC Golden had greatest plant biomass which also suggests that plant biomass production of semi-leafless cultivar is not limited by reduced photosynthetic area due to tendrils (Hedley and Ambrose 1979). PS0710091 had the least biomass for all three sampling periods. The same pattern was observed at the second sampling period (6-8 nodes stage). However, differences in per plant pea biomass might be due to differences in plant density, because each individual plant would have had access to proportionally greater resources in plots with lower weed and pea density. However, the semi-leafless cultivars, which produced the greatest biomass, were grown in plots with the greatest pea plant densities (Figure 2.1. A). There were no per plant LAI differences among the pea cultivars (Table 2.3, Figure 2.2 B).

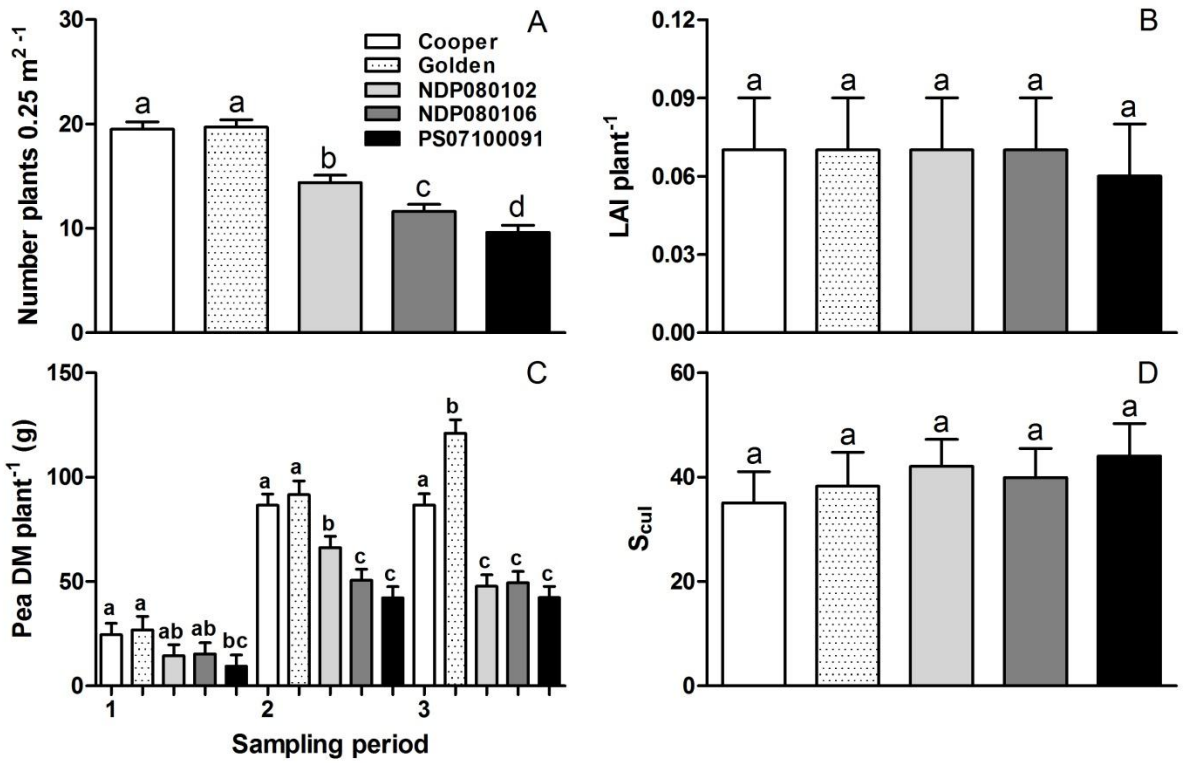

Figure 2.2. Mean ± s.e. (A) number of pea plants per 0.25 m^2 quadrat, (B) pea leaf area index (LAI), (C) pea shoot dry biomass (DM) per 0.25 m^2 quadrat, and (D) weed suppressive ability (Scul) for five pea cultivars (Cooper, CDC Golden, NDP080102, NDP080106, and PS0700091). Data were combined over years and locations. Means designated with different lower case letters differ at a 95% confidence level.

The Cooper and CDC Golden plant densities were greater than the other three cultivars (Figure 2.2 A). In many crop species, plant density influences the proportion of intercepted radiation and there is a consistent pattern observed with pea and other legume species for greater LAI at higher plant density (Ayaz et al. 2004). The total intercepted radiation for these two semi-leafless cultivars was greater on a quadrat basis (data not shown). Plant biomass production is often directly proportional to seasonal intercepted radiation (Ayaz et al. 2004), if light is the primary limiting resource. The normal leaf cultivars would be expected to have greater LAI per plant, but this was not the case in this experiment. Since per plant LAI did not differ among cultivars, differences in dry matter per plant among cultivars are likely due to factors other than

competition for light. According to McKay et al. (2003), if the competition for light is not the limiting factor then semi-leafless cultivars with greater vine length should be considered.

Weed suppressive ability (S_{cul}) and sensitivity of S_{cul} to weed density

S_{cul} did not differ among the pea cultivars when pea plant density was included as a covariate in the analysis (P = 0.7478, Figure 2.2 D). However, when pea density was not included as a covariate in the analysis, cultivars with greater plant density (Cooper and CDC Golden) had greater S_{cul} (data not shown). Thus, apparent differences in S_{cul} among cultivars (data not shown) were due only to differences in plant density and likely not due to differences in competitive ability on a per plant basis. As discussed above, differences in pea plant density were likely due to differences in seed size that led to differences in germination, emergence and seedling vigor. In this case, competitive ability against weeds is governed more by canopy competitiveness, which is a result of stand evenness due to even emergence, rather than due to competitive ability of the pea cultivars measured on a per plant basis. There were few differences in cultivar sensitivity of S_{cul} to changing weed density for cultivars (Table 2.4). A large regression coefficient or slope (positive or negative) indicates greater cultivar sensitivity to changes in weed density, so a lower value is desirable. Unfortunately, P-values for all cultivars except Cooper and PS07100091 indicated that the slopes of the sensitivity regressions did not differ from zero, indicating no sensitivity for these cultivars (Table 2.4). Only Cooper and PS07100091 had slopes different from zero. But a test of all lines showed that all the slopes were equal. So sensitivity of S_{cul} did not differ among cultivars.

Table 2.4. Mean value of field pea weed suppressive ability (S_{cul}) and sensitivity of weed suppressive ability combined across locations during 2012 only. Sensitivity was calculated as the slope of a linear regression against weedy check. R is the coefficient of correlation and P-values indicate whether or not the slopes of the lines differed from zero.

Cultivar	Sensitivity of S_{cul}	R	P
Cooper	-19.7 ± 7.3	0.25	0.013
CDC Golden	-14.3 ± 7.2	0.15	0.059
NDP080102	-8.6 ± 7.2	0.06	0.250
NDP080106	-11.3 ± 5.7	0.15	0.061
PS07100091	-13.2 ± 5.3	0.22	0.021

Weed biomass and weed LAI

There was significant effect of field pea cultivar on weed biomass, as well as an interaction between pea cultivar and sampling periods ($P < 0.0001$, Table 2.3). At the first sampling period, weed shoot dry matter did not differ for weeds grown among various pea cultivars (Figure 2.3 B). At the second and third sampling periods, weeds grown with Cooper, CDC Golden, and NDP080102 cultivars had accumulated less dry biomass than weeds grown with NDP080106 and PS0700091 cultivars. Curiously, weed LAI was consistently greater for Cooper, CDC Golden, and NDP080102 than for PS0700091 (Figure 2.3 A), indicating that weed LAI and weed shoot dry biomass were not well correlated. The increase in weed LAI for Cooper and CDC Golden was due to greater number of broad leaf weeds in the quadrat. Also, weed LAI was greatest when weeds were grown with the pea cultivars that had the greatest plant densities. This result is perplexing because the greater amount of pea LAI and pea biomass should have suppressed the weeds. This finding may be due to more soil moisture available in semi-leafless crop canopy that is available to small weeds growing below the canopy. Most of weeds grown with the semi-leafless cultivars were small and below the crop canopy; therefore these weeds did

not interfere with field pea light interception but those small weeds were taken into consideration for weed dry biomass and weed LAI.

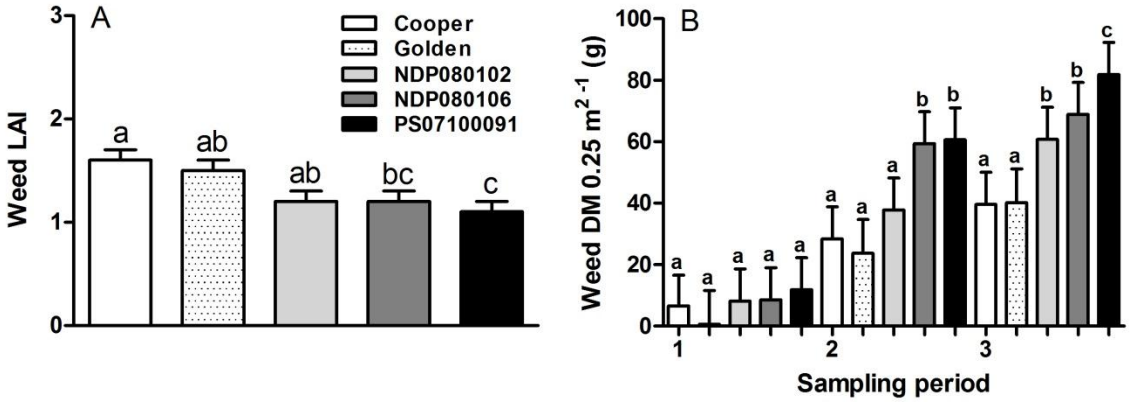

Figure 2.3. Mean ± s.e. (A) weed leaf area index (LAI) and (B) weed shoot dry biomass per 0.25 m^2 quadrat for weeds growing in plots with five pea cultivars (Cooper, CDC Golden, NDP080102, NDP080106, and PS0700091). Data were combined over years and locations. Means designated with different lower case letters differ at a 95% confidence level.

Pea yield components and lodging

Number of pods per plant differed among the five pea cultivars ($P < 0.0001$, Fig. 2.4). Cooper and CDC Golden had fewer pods per plant compared to NDP080102, NDP080106, and PS07100091 cultivars (Figure 2.4 A). There were no differences for yield per plant among the cultivars (Table 2.4, Figure 2.4 B). However, plot level yield differed among cultivars (data not shown). Cooper had the greatest plot yield at1300 kg ha^{-1} followed by CDC Golden at1160 kg ha^{-1}. PS0710091 had least plot level yield of 300 kg ha^{-1}. Two other cultivars NDP080102 and NDP080106 had intermediate plot level yield of 740 and 810 Kg ha^{-1}, respectively. These differences in yield can be explained by differences in pea densities (Figure 2.1.A) caused by differential emergence success.

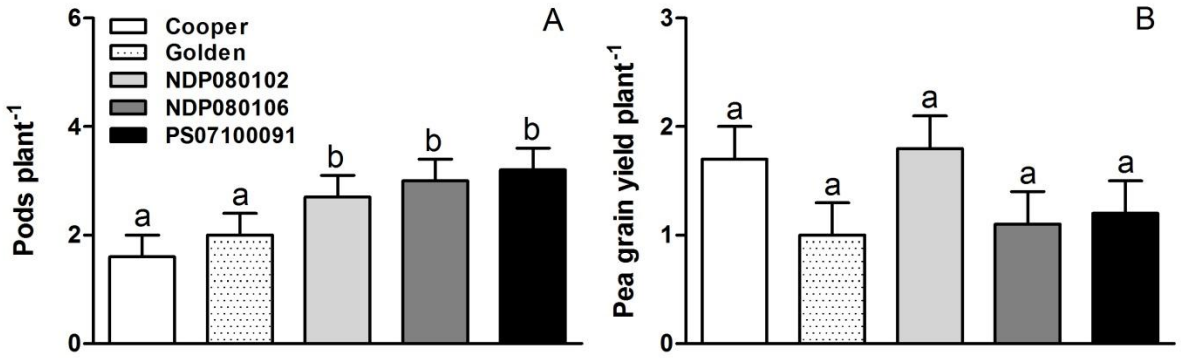

Figure 2.4. Mean ± s.e. (A) number of pods per pea plant and (B) pea grain yield per plant for five pea cultivars (Cooper, CDC Golden, NDP080102, NDP080106, and PS0700091). Data were combined over years and locations. Means designated with different lower case letters differ at a 95% confidence level.

These results indicate that the semi-leaf cultivars, Cooper and CDC Golden, had substantially reduced lodging compared to the normal-leaf cultivars (NDP080102, NDP080106, and PS07100091). These results agree with expectations, since semi-leafless cultivars have more tendrils and thus intertwine to increase plant support. This characteristic is agronomically advantageous because it leads to less disease and greater harvest ease.

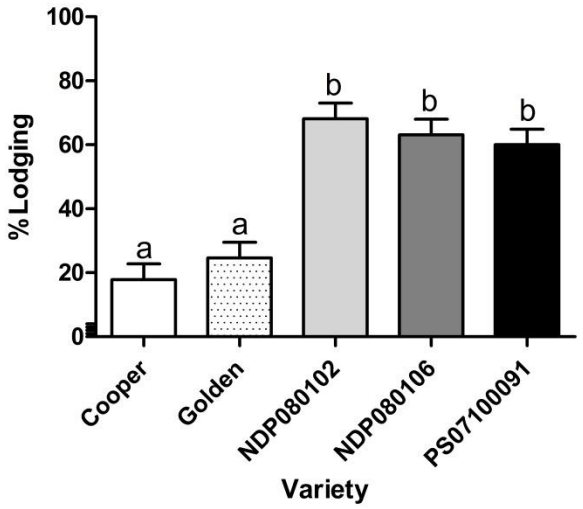

Figure 2.5. Mean ± s.e.% field pea lodging measured in plots containing five pea cultivars grown during 2012 (data combined over Dickinson Research Extension Center and Carrington Research Extension Center locations). For lodging ratings, 0% signifies no lodging, 50% signifies pea stems bent at a 45 degree angle from the ground, and 100% signifies pea stems bent horizontal to the ground. Means designated with different lower case letters differ at a 95% confidence level.

Objective 2: Greenhouse study for assessing field pea competitive ability

All five pea response variables (per plant vegetative dry matter, number of pods per plant, grain yield per plant, pea shoot height, and % lodging) were affected by treatment (pea cultivar + or – common lambsquarters) (Table 2.5). Cooper produced greater vegetative shoot dry matter and greater yield than NDP080106, regardless of common lambsquarters presence (Figure 2.6 A and C). The presence of weeds reduced vegetative shoot dry matter and grain yield regardless of pea cultivar type. Also, differences in pea grain yield mirrored differences in vegetative shoot dry matter, indicating that treatments likely did not affect the harvest index of these field pea cultivars.

Peas grown without common lambsquarters produced greater numbers of pods than peas grown with common lambsquarters (Figure 2.6 B). However, Cooper grown without common lambsquarters produced fewer pods than NDP080106 grown without common lambsquarters, while conversely Cooper grown with common lambsquarters produced more pods than

NDP080106 grown without common lambsquarters. This is likely due to more interplant support in Cooper with common lambsquaters that led to greater utilization of intercepted solar radiation. This finding is in agreement with Ayaz et al. (2004) that dry matter and seed yield is strongly correlated to total seasonal intercepted PAR. Also, when the two cultivars were grown without weeds, Cooper had greater yield than NDP080106 even though NDP080106 produced more pods than Cooper. But when common lambsquarters were present, Cooper produced greater yield compared to NDP080106 and also produced more pods. This difference in result from the field study (i.e., yield/ plant did not differ among cultivars in the field study) can be explained by the fact that water was not a limiting resource in the greenhouse study. That may be probably why we observed greater yield from Cooper under ideal greenhouse conditions. Pea height was reduced when plants were grown with common lambsquarters, but this effect didn't differ among pea cultivar type (Figure 2.6 D). Weed shoot dry matter and weed height did not differ between pea cultivar type (P = 0.280 and P = 0.070, respectively, data not shown).

Table 2.5. Analysis of variance results for tests of treatment (pea cultivar + or – common lambsquarters) effects on pea vegetative shoot dry matter, pod number per pea plant, pea grain yield per plant, pea shoot height, and % pea lodging.

Response variable	F	P
Pea vegetative DM plant^{-1}	56.9	<0.0001
Number of pods pea plant^{-1}	29.8	<0.0001
Pea yield plant^{-1}	36.2	<0.0001
Pea shoot height	25	<0.0001
Pea % lodging	40	<0.0001

Results suggest that weed suppressive ability did not differ between the two cultivars. Moreover, mean grain yield for Cooper was reduced by 43% when common lambsquarters were present and mean grain yield for NDP080106 was reduced by 56% when common lambsquarters were present (Figure 2.6 C). This suggests that Cooper may have been slightly more tolerant of common lambsquarters than NDP080106, but this difference was probably not substantial.

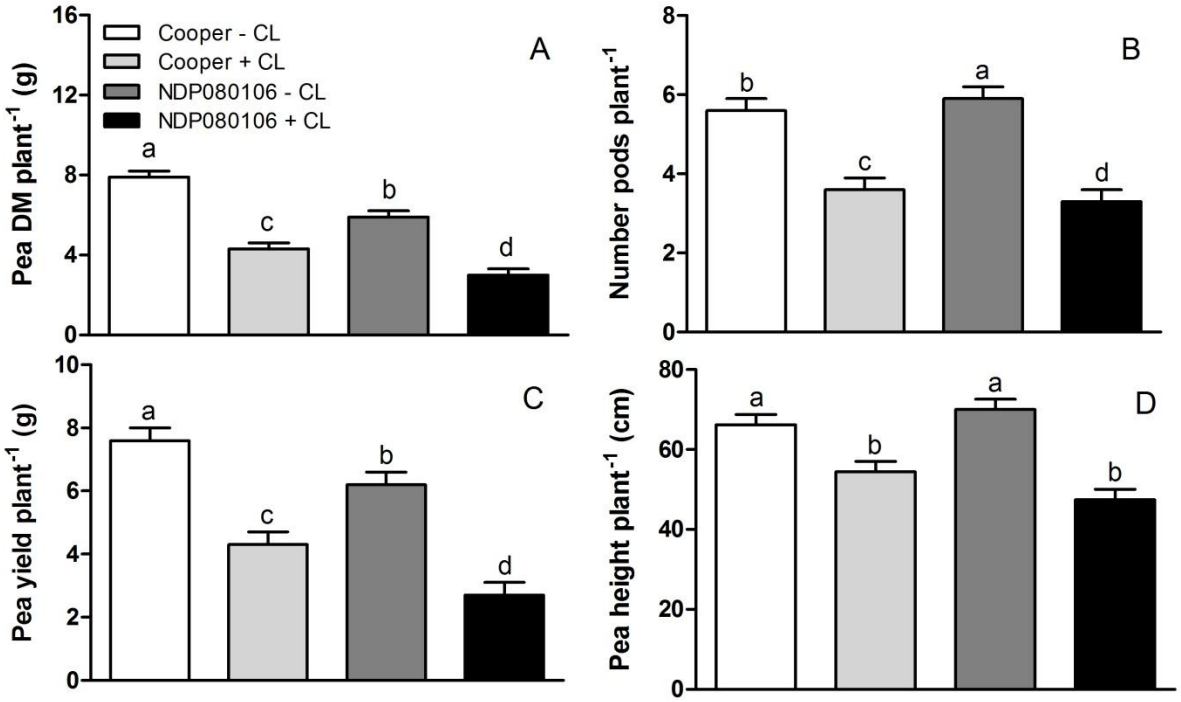

Figure 2.6. Treatment effects on mean ± s.e. (A) vegetative shoot dry matter per plant, (B) number of pods per plant, (C) pea grain yield per plant, and (D) pea shoot height. Treatment consisted of two pea cultivars (Cooper and NDP080106) grown with or without common lambsquarters (CL) under controlled greenhouse conditions. All data are combined over three experimental runs. Means designated with different lower case letters differ at a 95% confidence level.

For the Cooper pea cultivar, lodging was only about 20%, regardless of weed presence (Figure 2.7). Lodging for the NDP080106 variety was greater than for Cooper, but NDP080106 pea plants grown with common lambsquarters experienced 28% less lodging than plants grown without common lambsquarters (Figure 2.7). Cooper is a semi-leafless cultivar in which leaflets

are replaced by tendrils, making the plants less susceptible to lodging by enabling clinging onto neighboring plants for support. This suggests that semi-leafless cultivars have significantly better standing ability than normal leaf cultivars (Heath and Hebblethwaite 1985; Uzun and Acikgoz 1998). There is a correlation between lodging and yield reduction because of two reasons. First, lodging of crop plants on top of one another causes significant reduction in intercepted solar radiation and consequently crop yield. A second possible explanation of yield reduction is post flowering loss of dry matter due to rotting.

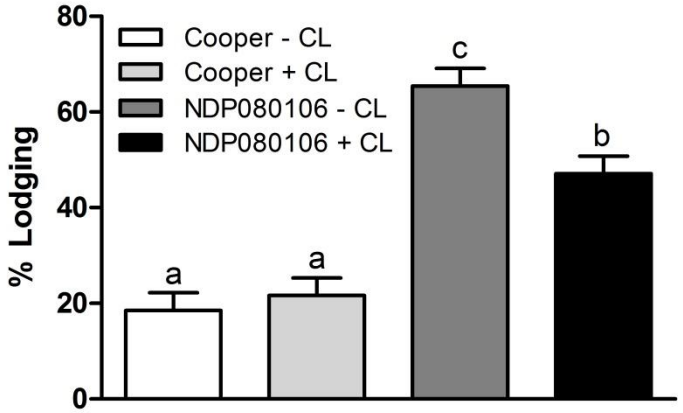

Figure 2.7. Treatment effects on mean ± s.e. % lodging for two pea cultivars (Cooper and NDP080106) grown with or without common lambsquarters (CL) under controlled greenhouse conditions. All data are combined over three experimental runs. Means designated with different lower case letters differ at a 95% confidence level.

Summary and Conclusion

Pea cultivars with greater competitive ability should be associated with reduced weed LAI or weed biomass when compared to the weedy check and should have superior seed vigor. As seedling mortality occurs in almost all cultivars, a cultivar that has low seedling mortality rate and good emergence will be preferred over other cultivars. In this study, Cooper and CDC Golden had good emergence because of inherent seed vigor. Thus, these two cultivars could be considered as competitive cultivars, because optimal emergence produced more competitive

canopies with greater S_{cul}. Among the other three cultivars, PS07100091 had poorest emergence in spite of over-seeding. That is probably why PS0710091 did not have good initial plant establishment. At the second and third sampling periods, weed biomass in Cooper and CDC Golden (both semi-leafless cultivars) plots was reduced compared to the weedy check. PS07100091, a normal leaf cultivar, had greatest weed biomass and weed LAI at the third destructive harvest, while the number of pods per plant was greater that of the other cultivars. However, the greater pod count per plant in PS07100091 did not change the overall yield per plant. A cultivar that is recommended for organic producers should germinate and emerge reliably over a wide range of conditions since this will ensure a plant canopy that is competitive against weeds. In this study, Cooper and CDC Golden had reliable germination, uniform emergence, and formed the most competitive pea canopies. In terms of per-plant competitive ability, however, it is very difficult to arrive at any conclusions because of uneven density among the cultivars. However, these results indicated that when adjusted for density, S_{cul} and sensitivity did not differ among the tested cultivars.

This weed competition field study was limited in the sense that field pea density was not optimal and only five cultivars were included in this study. Also, making assumptions about competitive abilities based on one optimum density does not represent what will happen at other plant densities. Future studies need to be done on other morphological traits that make a pea plant more competitive against increased weed pressure, such as vine length and branching abilities. This study does not provide a significant amount of conclusive information about differences in competitive ability per plant among pea cultivars, but these results provide preliminary data on factors that can make a difference in competitive abilities. Based on these results, more attention should be given to semi-leafless cultivars with good seed vigor and even

emergence under a wide range of environmental conditions under organic management scenarios.

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CHAPTER 3. PRELIMINARY SCREENING FOR ALLELOPATHIC POTENTIAL OF TWO SOYBEAN (*Glycine max* L.) CULTIVARS AGAINST GREEN FOXTAIL (*Setaria viridis* L.) AND YELLOW FOXTAIL (*Setaria glauca* L.)

Abstract

Greenhouse pot experiments were conducted for preliminary screening for allelopathic potential of two soybean cultivars against green foxtail and yellow foxtail. Five soybean plants were established in the center of each pot, and twelve green or yellow foxtail plants were established in a circle around the soybean plant. Experiments were repeated twice and data were combined to assess the treatment effect of soybean cultivars on weed shoot height and dry shoot biomass. The results indicated that green foxtail height and dry biomass were not affected by either soybean cultivar, whereas yellow foxtail height was reduced by both Viking 1706 and 1832. However, dry biomass of yellow foxtail was not reduced by Viking 1832. These results suggest that only Viking 1706 substantially affected yellow foxtail performance. This preliminary assessment suggests that the Viking 1706 soybean cultivar may have some allelopathic activity against yellow foxtail, but not against green foxtail.

Introduction

Allelopathy refers to chemically mediated interactions among plants, including those mediated by microorganisms and lower plants (Molisch 1937). These chemical interactions can be inhibitory and/or stimulatory. There are different types of allelopathic interactions among plants such as, weed-weed, crop-weed, and crop-crop. Crop-weed allelopathy has received great attention since the 1980s across the world. Recently studies have been focused on development of weed management strategies using allelopathic potential of crop cultivars against weeds. Putnam and Duke (1974) first emphasized the possibility of using allelopathic crop cultivars for

effective weed suppression. There are many weeds species that exhibit allelopathic activity against neighboring plants, such as velvetleaf (*Abutilon therophrasti* Medic.) and quackgrass (*Agropyron repens* L.) (Gabor and Veatch 1981; Gressel and Holm 1964). Similarly, many field crops cultivars possess the ability to inhibit weed growth via chemical exudates. Therefore, growing allelopathic crop and cultivars can be an inexpensive tool to control weeds under organic cropping systems (Rose et al. 1984). For example, wheat (*Triticum aestivum* L.), oats (*Avena sativa* L.), corn (*Zea mays* L.), grain sorghum (*Sorghum bicolor* L.), and soybean (*Glycine max* L.) have been shown to have allelopathic potential. Research by Guenzi and McCalla (1962) found that soybean hay can inhibit 45% of wheat shoot growth and 30% of wheat root growth. Another study by Maun (1977) showed that 6-10 week old soybean plants reduced the height and dry matter production of barnyard grass (*Echinochloa crusgalli* L.) by 94%. These studies did not separate the possibility of competition from possible allelopathy.

Allelopathic interference is difficult to separate from competition under field and greenhouse conditions (Radosevich et al. 1974). Weed suppression under field conditions by a neighboring plant is often caused by a combination of allelopathy and competition (Weston 2005). Therefore conclusive demonstration of allelopathy is usually not possible using field experiments alone. Allelopathy experiments under greenhouses are also not entirely conclusive because results cannot be easily extrapolated to field conditions where complex interacting effects of climate, soil and effect of microorganisms are not understood (Colquhoun 2006). Due to these problems in research methodology, relatively few studies have been conducted to separate the effect of competition from allelopathy.

Research by Creamer et al. (1996) separated the effect of allelopathy from competition in rye (*Secale cereal* L.) and barley (*Hordeum vulgare* L.). They conducted high-performance

liquid chromatograph analysis (HPLC) and seed germination bioassay to confirm that rye can be used as a control treatment without having allelopathic effect. The potential allelochemical from rye had been leached out by suspending the residues in distilled water and methanol solution. HPLC were conducted to make sure that no allelochemical were retained with rye residue. In this way, they separated the allelopathic effect from complex crop interference. They found that inhibition of yellow foxtail (*Setaria glauca* L.) emergence by rye residue was only due to competition whereas a combination of competition and allelopathy due to barley reduced the yellow foxtail emergence by 81%.

Weeds are a major problem causing yield losses in organic soybean production (Archer and Kludze 2006). In addition, weeds also pose serious harvesting difficulties and affect the storability of soybean (Burnside 1972). Significant soybean yield loss in has been reported due to different density and duration of weed competition (Burnside 1968). Due to a high profit margin for organic soybeans, total acreage of organic soybean production is increasing (Archer et al. 2007). Organic growers have very few weed management options due to restricted use of inorganic herbicides (Jordan 1993). Growers have to rely on other management tactics such as the use of more competitive soybean cultivars and, potentially, the use of allelopathic soybean cultivars. Highly competitive and/or allelopathic cultivars are useful for both conventional as well as organic growers, because these cultivars may help reduce the number of herbicide applications required (Norsworthy and Shipe 2006). Burnside (1972) also reported the difference in competitive ability of 10 soybean cultivars against green foxtail and tall waterhemp.

The objective of this research was to determine the allelopathic potential of two soybean cultivars (Viking 1706 and Viking 1832) against two weed species, green and yellow foxtail (*Setaria virdis* [L.] Beauv.). The motivation for this research came from a South Dakotan farmer,

who observed that Viking 1832 appeared to inhibit germination and growth of yellow foxtail more than other soybean cultivars. Therefore, the hypothesis of this research was that green and yellow foxtail suppression would be observed when these species were grown with Viking 1832, but not with Viking 1706.

Materials and Method

Plant culture and measurements

A controlled greenhouse study was conducted as a preliminary study to evaluate the allelopathic effect of two soybean cultivars, Viking 1706 and Viking 1832, on yellow and green foxtail performance. Plants were grown in plastic pots containing 10 kg of Ulen fine168, sandy loam (sandy, mixed, frigid Aeric Calciaquolls) soil. The dimensions of the pots were 45 cm (height) by 25 cm (diameter). Eight soybean seeds were planted at a 25mm depth in the center of pot. Twenty seeds of green or yellow foxtail were planted in a circle about 10 mm deep around the soybean seeds. For a weedy check comparison, one pot per rep containing each weed species was planted without soybean. A day length of 16 hours were maintained in the greenhouse for four weeks by HID (1000 W metal halide) supplementary lights having at least 150 µmol m^{-2} s^{-1} of photosynthetically active radiation. Temperatures in the greenhouse were adjusted to 14° C for daytime and 10° C during the night time. Watering of pots was carried out to field capacity as needed. Excessive watering was avoided to prevent the leaching of allelochemicals from the roots. Each day, 300 ml. of water was added to each pot based on evapotranspiration calculation. Emergence times for each cultivar and weed species were noted. After 1 week, soybean plants were thinned at the two leaf stage to five plants per pot and weed plants to 12 plants per pot. To avoid competitive interactions between soybean plants and weeds, experiments were terminated 4 weeks after planting (Rose et al. 1984).

Statistical Analysis

The experiment was conducted as randomized complete block design with four replicates. The experiment was repeated two times and data were combined for analysis. Treatment effects on weed response variables (height and shoot dry biomass) were tested using analysis of variance via Proc Mixed (SAS version 9.3). Treatment (yellow foxtail or + or □green soybean) was considered a fixed effect; replication and experimental run were considered random effects. Prior to ANOVA, all data were subjected to diagnostic tests using Proc Univariate (SAS version 9.3). Variance of residuals was assessed via Levene's test and normality was assessed by computing a Shapiro-Wilks statistic. Data conformed to the assumptions of ANOVA and thus were not transformed for analysis. When ANOVA F-tests were significant, means were separated with the lsmeans statement in Proc Mixed using specific preplanned contrasts (yellow foxtail check vs. yellow foxtail grown with Viking 1706, yellow foxtail check vs. Viking 1832, green foxtail check vs. green foxtail grown with Viking 1706, and green foxtail check vs. green foxtail grown the Viking 1832). Means were considered different at the 95% confidence level.

Results and Discussion

Treatment (green or yellow foxtail + or – soybean) influenced weed dry biomass (F=3.07 P=0.0211). Green foxtail height was not affected by interaction with Viking 1706 soybean (P=0.1021, Figure 3.1) or Viking 1832 soybean (P=0.2926). Conversely, both Viking 1832 (P=0.0198) and Viking 1706 (P=0.0237) caused a 19% reduction in yellow foxtail height (Fig. 3.1).

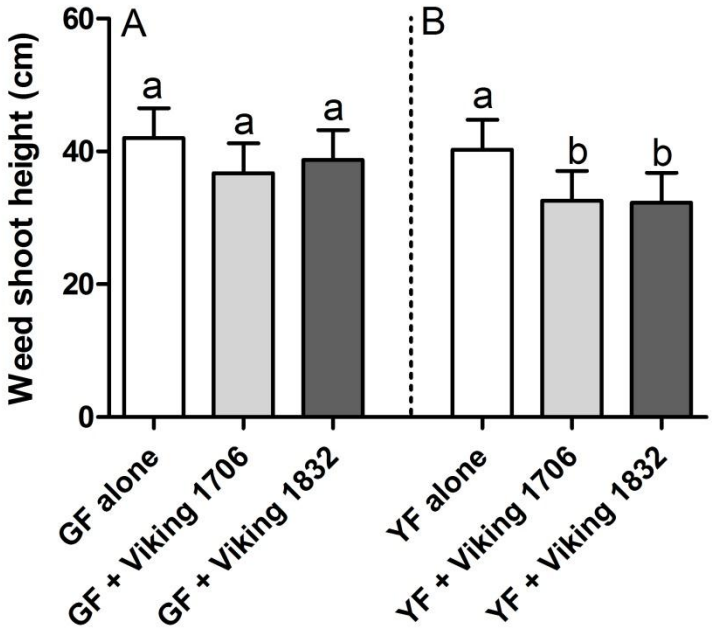

Figure 3.1. Mean ± s.e. weed shoot height for green foxtail (GF), and yellow foxtail (GF) as influenced by interaction with (A) Viking 1706 or (B) Viking 1832 soybean cultivars. Comparisons made were 1) GF alone vs. GF grown with Viking 1706, 2) GF alone vs. GF grown with Viking 1832, 3) YF alone vs. YF grown with Viking 1706, and 4) YF alone vs. YF grown with Viking 1832. Means designated with different lower case letters differ at a 95% confidence level and labels pertain only to the specific comparisons listed, not all possible pairwise comparisons.

Treatment (green or yellow foxtail + or – soybean) influenced weed dry biomass (F=6.19 P=0.0003). Yellow foxtail exposed to four weeks of crop-weed interference from Viking 1706 soybean produced a 36 % less weed biomass compared to yellow foxtail grown alone (P <0.0001, Figure 3.2), whereas interference from Viking 1832 soybean did not influence yellow foxtail weed biomass (P=0.0810, Fig. 3.2). Green foxtail biomass was not influenced by interference from growing with Viking 1706 soybean (P = 0.1720, Figure 3.2) or with Viking 1832 soybean (P=0.4621, Figure 3.2).

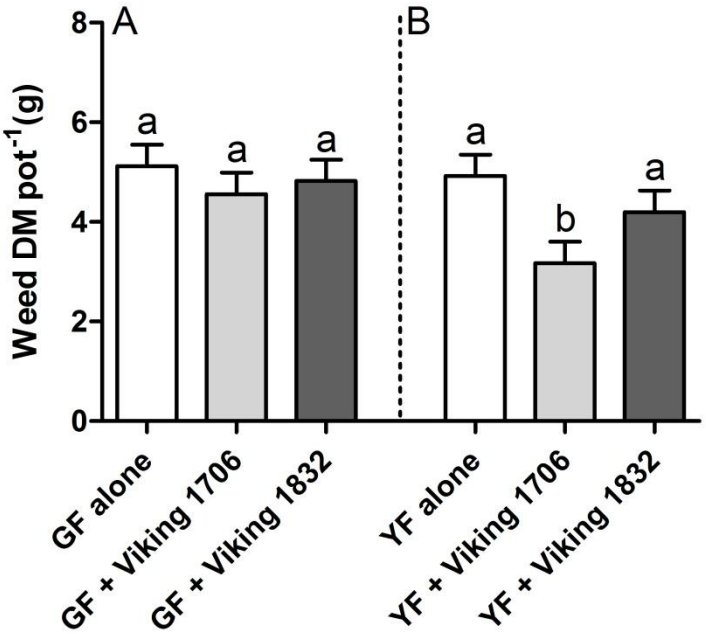

Figure 3.2. Mean ± s.e. weed shoot dry matter (DM) for (A) green foxtail (GF), and (B) yellow foxtail (GF) as influenced by interaction with Viking 1706 or 1832 soybean cultivars. Comparisons made were 1) GF alone vs. GF grown with Viking 1706, 2) GF alone vs. GF grown with Viking 1832, 3) YF alone vs. YF grown with Viking 1706, and 4) YF alone vs. YF grown with Viking 1832. Means designated with different lower case letters differ at a 95% confidence level and labels pertain only to the specific comparisons listed not all possible pairwise comparisons.

These results suggest that only Viking 1706 and not Viking 1832 affected yellow foxtail performance as measured by dry biomass. This interpretation is contrary to the results for height, which suggested that both soybean cultivars influenced weed performance as gauged by height measurement. Is height or biomass a better measure of overall plant growth? Height is usually measured as a proxy for size, but biomass is a more reliable indicator of size. A true allelopathic effect would probably result in both reduced height and reduced biomass. The farmer who provided the soybean seeds for this study claimed he only saw the allelopathic effects with Viking 1832, not 1706. But if total biomass is a more robust indicator of growth than height, we might conclude that only Viking 1706 seems to have potential allelopathy against yellow foxtail. This result runs counter to the SD farmer's observation that only Viking 1832 appeared to have

allelopathic effects. A possible explanation for the farmer's observation is that, in this experiment, Viking 1832 appeared to have more bushy and vigorous growth, unlike Viking 1706, which was taller but more spindly and less robust (Anand, personal observation). Therefore, in the field, Viking 1832 may be a more effective competitor against weeds because it may close the canopy and shade weeds more quickly than Viking 1706.

Possible allelopathic interactions between soybean cultivars and green or yellow foxtail have not been previously investigated. However several studies have reported allelopathic or potentially allelopathic impacts of soybeans on other weed species. Massantini et al. (1977) reported putative alleopathy in ten different soybean lines against *Helminthus echioides* St. Another study found that soybean residues and leachates from soybean residues inhibited wheat growth and reduced yields 19 to 29%, depending on rate of residue or leachate (Huber and Abney, 1986). Rose et al. (1984) demonstrated that soybean root exudates inhibited growth of velvetleaf (*Abutilon theophrasti* L.) but not foxtail millet (*Setaria italica* L.). The same study showed that incorporation of soybean residues into field soil and exposure to undiluted soybean plant extracts both inhibited germination of velvetleaf and foxtail millet. Experiments conducted by Burnside (1972) found differences among ten cultivars in the ability of soybeans to compete with green foxtail. But this study was not designed to separate competitive effects from allelopathic effects, so the observed effects could have been partially due to allelopathy but on the other hand may have been due only to competition.

This preliminary assessment showed that soybean cultivars may have some allelopathic activity against yellow foxtail but not green foxtail. One indication that allelopathy and not competition was present is that green foxtail height and biomass were not affected by either soybean cultivar. However, additional studies would be required to establish whether or not

Viking 1706 or Viking 1832 exert true allelopathic action against yellow foxtail, as the experimental approach was designed to minimize but perhaps not entirely remove the effects of competition from the experiment. One approach that could be used would be to grow soybeans in pots for a period of time then harvest the soybeans and plant weed seeds into the same pots and assess effects on growth compared to a control. An additional approach would be to incorporate soybean residues into soil and test the effects on weed germination and growth. Also, soybean plant extracts could be tested for effects on weed germination in petri plates. All these methods were used to assess soybean allelopathy by Rose et al. (1984).

Another issue to confront is, even if some soybean cultivars exhibit allelopathic activity against weeds, are the effects great enough to forego other weed control operations? If crop allelopathy is seen with some weeds and not others, the weeds that are unaffected will still need to be controlled. More successful implementations of allelopathy usually involve crops that are especially detrimental to one particular weed that is a large problem that crop (e.g., rice (*Oryza* spp) and barnyard grass or wheat and Italian ryegrass (*Lolium multiflorum* L.)] (He et al. 2012; Worthington and Reberg-Horton 2013). Also, slight reductions in weed growth are not the same as weed mortality. To be highly effective, an allelopathic effect would ideally need to result in weed mortality, not just a minor reduction in growth or vigor. The results of this study only showed modest reduction of height and biomass for yellow foxtail grown with Viking 1706 soybean. In reality, these modest reductions in growth probably would not lead to the ability to forego a weed control operation. However, one possible scenario is that modest reductions in weed growth could allow an operation such as tillage to be conducted later in the season, waiting for even more weeds to emerge. In this case, under organic production methods, such an effect could potentially serve to reduce the number of tillage operations necessary. So soybean

allelopathy could have some benefit for organic farmers given such a scenario, but the other agronomic characteristics of the allelopathic cultivar, such as seedling vigor and yield potential, would need to be considered as well.

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